MULTIMEDIA UNIVERSITY

STUDENT ID NO

MULTIMEDIA UNIVERSITY

FINAL EXAMINATION

TRIMESTER 2, 2015/2016

EMF2026 – MICROWAVE DEVICES

(MCE)

4 MARCH 2016
9:00 A.M -11:00 A.M.
(2 Hours)

INSTRUCTION TO STUDENT

1.This Question paper consists of 8 pages including cover page with 4 Questions only.

2. Attempt all **FOUR** questions. All questions carry equal marks and the distribution of the marks for each question is given.

3. Please print all your answers in the answer Booklet provided.

Question 1

(a) Figure Q1(a) shows the temperature dependence of carrier concentration for both intrinsic and extrinsic semiconductor. Critically analyse the graph by explaining the shape of the graph for the 3 regions which are region I, region II and region III. The explanation should involve both electrons and holes carrier concentration.

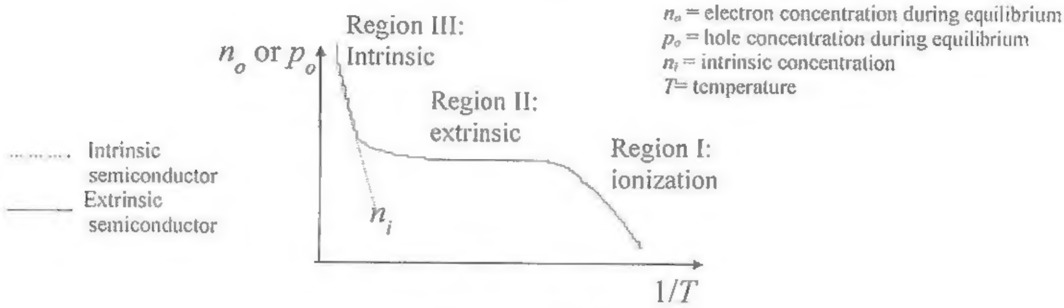

Figure Q1(a)

[7 marks]

(b) At T = 300 K, the doping concentrations of acceptors, N_a and doping concentration of donors, N_d in silicon semiconductor are 0 and 10^{17} cm^{-3} respectively. Given that the mobility of electrons, μ_n = 1350 cm^{2}V^{-1}s^{-1}, the mobility of holes, μ_p = 480 cm^{2}V^{-1}s^{-1} and the intrinsic concentration, n_i = 1.5x10^{10}cm^{-3},

(i) find the equilibrium hole concentration, p_0 at 300K.

[2 marks]

(ii) identify the Fermi level, E_F relative to the intrinsic level, E_i

[2 marks]

(iii) sketch the resulting energy band diagram based on Qb(ii).

[3 marks]

(c) Calculate the probability that a state in the conduction band is occupied by an electron and calculate the thermal equilibrium electron concentration in silicon at T= 300K. Assume the Fermi energy is 0.25eV below the conduction band. The value of N_c for silicon at T =300K is N_c=2.8x10^{19}cm^{-3}.

[5 marks]

(d) Consider an intrinsic semiconductor with electron concentration, n_i and hole concentration, p_i, prove that $n_i^2 = N_C N_V e^{-E_g/kT}$.

[6 marks]

Continued...

Question 2

(a) A silicon pn-junction at T= 300K has the following parameters. Calculate the minority electron diffusion current at the space charge edge.

Acceptor Concentration, N_a	$5\text{x}10^{16}\text{cm}^{-3}$
Donor Concentration, N_d	$1\text{x}10^{16}\text{cm}^{-3}$
minority carrier electron diffusion coefficient, D_n	$15\text{cm}^2/\text{s}$
minority carrier hole diffusion coefficient, D_p	$10\text{cm}^2/\text{s}$
minority carrier electron life time, τ_{no}	$5\text{x}10^{-7}\text{s}$
minority carrier hole life time, τ_{po}	$1\text{x}10^{-7}\text{s}$
Cross –sectional area, A	10^{-3}cm^2
Forward bias voltage, V_a	0.625 V

[5 marks]

(b) Figure Q2(b) shows the energy band diagrams and I-V characteristics of the tunnel diode at both the zero bias (a) and reverse bias (b). Critically analyse the graph by explaining the shape of the graph. The explanation should involve an energy level.

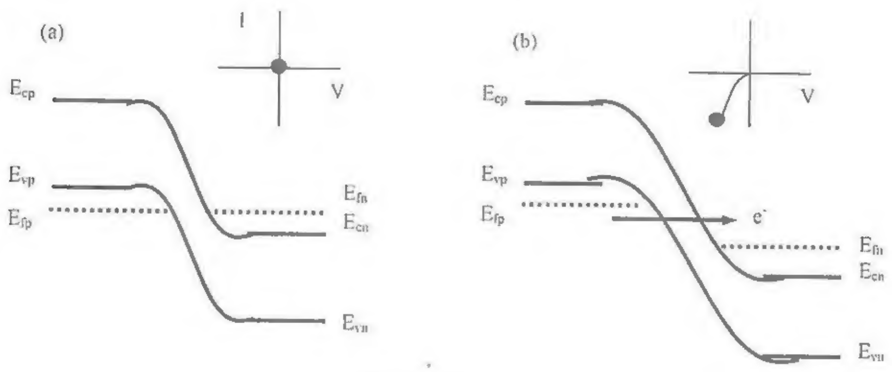

Figure Q2(b)

[4 marks]

Continued...

(c) By referring to the equivalent circuit as shown in Figure Q2(c), derive an expression for the short-circuit current gain, G_i^{SC} of a bipolar transistor.

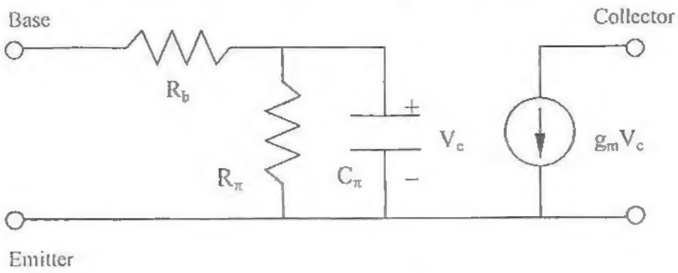

Figure Q2(c)

[Hint: $G_i^{SC} = \left|\frac{I_c}{I_b}\right|_{Vce=0}$ for a bipolar transistor]

[8 marks]

(d) The hybrid-pi equivalent model as shown in Figure Q2(d) is commonly used in the normal active mode of the common emitter configuration of microwave bipolar transistor. Simplify the model for operation at low frequency.

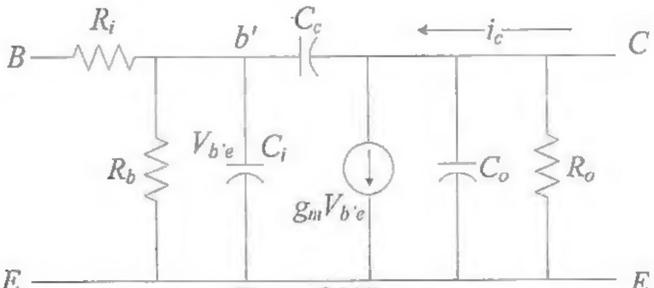

Figure Q2(d)

[4 marks]

(e) Explain how the opposing effect of drift and diffusion current in a PN junction, leads to zero net junction current at equilibrium.

[4marks]

Continued...

Question 3

(a) From the following Poisson's equation which is used for the voltage in the *n*-channel of Junction Field-Effect Transistors (JFETs) in terms of volume charge density, derive the pinch-off voltage equation, V_p as a function of doping concentration, N_d and the channel height, a.

$$\frac{d^2V}{dy^2} = -\frac{\rho}{\varepsilon_s} = -\frac{qN_d}{\varepsilon_s}$$

where

V = volume
ρ = volume charge density in coulombs per cubic meter
q = charge in coulombs
N_d = electron concentration in electrons per cubic meter
$\varepsilon_s = \varepsilon_0\varepsilon_r$ = permittivity of the material in farads per meter

[5 marks]

(b) An n-channel JFET has the following parameters:

Electron density:	$N_d = 2\times10^{17}$ cm^{-3}
Dielectric constant:	$\varepsilon_r = 11$
Channel height:	$a = 0.32\times10^{-4}$ cm
Channel length:	$L = 5\times10^{-4}$ cm
Channel width:	$Z = 40\times10^{-4}$ cm
Electron mobility:	$\mu_n = 680$ cm^2 / V·s
Drain voltage:	$V_d = 9$ V
Gate voltage:	$V_g = -2$ V
Built-in voltage:	$\varphi_0 = 0.8$ V

Find:

(i) The pinch-off voltage in volts.

[1 marks]

(ii) The pinch-off current in mA.

[1 marks]

(iii) The drain current in mA.

[2 marks]

(iv) The saturation drain current in mA.

[2 marks]

Continued...

(c) A Silicon *n-p-n* transistor has the following parameters:
Collector current, $I_C = 5\text{mA}$
Common-emitter current gain factor, $h_{fe} = 100$
Base width, $W = 9.8 \times 10^{-5}$ cm
Electron mobility, $\mu_n = 1600$ cm^2/V·s

The transistor is operating at 300K. Calculate:

(i) The mutual conductance, g_m
[1 mark]

(ii) The input conductance, g_b
[2 marks]

(iii) The electron diffusion coefficient, D_n
[2 marks]

(iv) The diffusion capacitance, $C'_{b'e}$.
[2 marks]

(d) Figure Q3(d) shows Ridley-Watkins-Hilsum (RWH) scenario where the carriers drift from the left to right of transferred electron devices. Describe the consequences if a constant high voltage is applied across the sample.

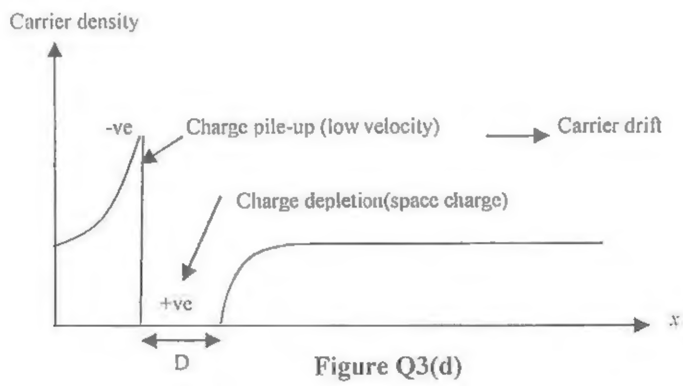

Figure Q3(d)

[4 marks]

(e) In bipolar junction transistor (BJT), critically provide the reason why *n-p-n* structure is preferred for high frequency applications.

[3 marks]

Continued...

Question 4

(a) Figure Q4(a) shows a reflex klystron microwave tubes. Describe the consequences if the buncher gap width, *d* is increased.

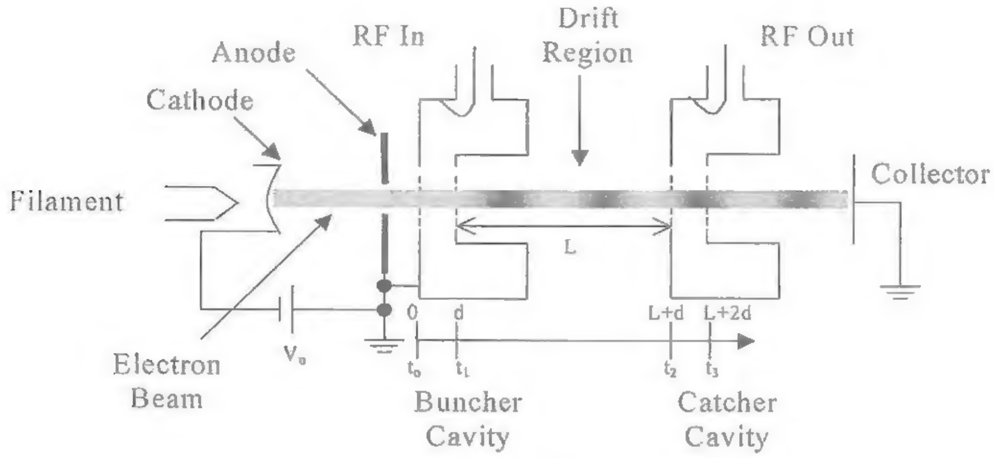

Figure Q4(a)

[3 marks]

(b) An Impact Ionization Avalanche Transit-Time (IMPATT) diode has a drift length of 2 μm. The diode is operated at dc bias voltage of 100V and dc current of 200 mA. The efficiency is 15%. Determine:

(i) the drift time of the carriers (given the drift velocity is 10^7cm/s) .

[2 marks]

(ii) the operating frequency of the diode.

[2 marks]

(iii) the output power.

[2 marks]

Continued...

(c) A two-cavity klystron amplifier is tuned at 3 GHz. The drift space length is 2 cm and beam current of 25 mA. The catcher voltage is 0.3 times the beam voltage. Assume the beam coupling coefficient β=1, bunching parameter X = 1.841, and J_1 (X) = 0.582. For mode number N = 5 ¼, compute the following.

(i) dc beam velocity.

[3 marks]

(ii) beam voltage.

[2 marks]

(iii) power output.

[2 marks]

(iv) efficiency.

[2 marks]

(d) Figure Q4(d) shows the drift velocity versus electric field intensity for carriers in Avalanche Transit Time devices made of Garlium Arsenide (GaAs) and Silicon (Si). Analyze the graph by determining the effect of electric field and significant differences between the 2 types.

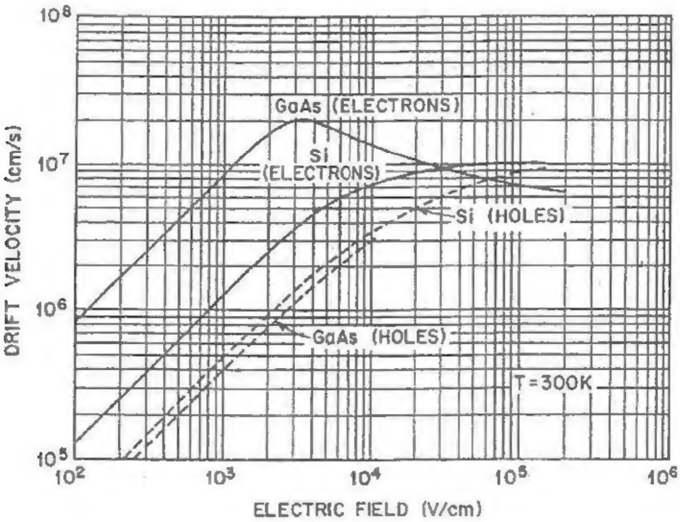

Figure Q4(d)

[4 marks]

(e) In an impact ionization avalanche transit-time (IMPATT), critically provide reason it is generally not used for local oscillators in microwave and millimeter-wave receivers.

[3 marks]

End of Paper